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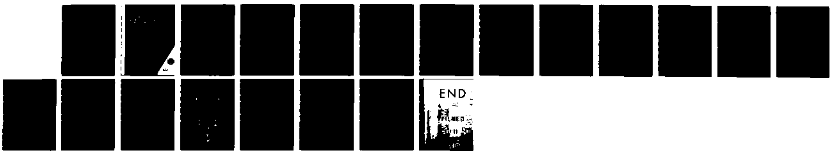

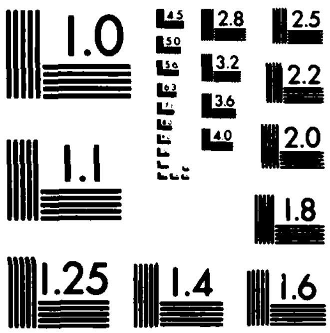
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TN 6300-1-83

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TECHNICAL NOTE

# ELECTRONICS REDESIGN OF THE NUS MODEL 1020 HULL-MOUNTED SOUND VELOCIMETER

STANLEY E. RAFFA

MAY 1983



PREPARED BY
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PREPARED FOR
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NAVAL OCEANOGRAPHY COMMAND
NSTL STATION, BAY ST. LOUIS, MS 39529

The effort discussed in this report was performed in support of the Ocean Surveys Program. The instrumentation described provides surface sound velocity reference measurements for use in bathymetric surveys. If further information on this topic is desired, contact Commanding Officer, Naval Oceanographic Office, Maintenance Engineering Division, NSTL Station, Bay St. Louis, MS 39522, Attention: Mr. Adolph H. Klein (FTS 494-4465, AV 485-4465).

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The redesign of the electronics in the NUS model 1020 hull-mounted sound velocimeter is described. Calibration test results are provided. The test data demonstrate that the redesign meets the accuracy specifications of the original instrument.

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## INTRODUCTION

The Instrumentation and Metrology Branch of the Naval Oceanographic Office (NAVOCEANO) provides depot level maintenance support for oceanographic sensor instruments used in NAVOCEANO survey operations. The Nusonics Model 1020 hull-mounted sound velocimeter was one of the instruments supported. However, when the manufacturer went out of business and all spares had been exhausted, support of the instrument, as configured, was impossible because all of the electronics circuits were potted in a hard epoxy and no circuitry documentation was available. Since the transducers and housing were still in excellent condition, redesign of the electronics only was undertaken. The redesign goals were to provide an instrument which met the original specifications, was technically documented and supportable regarding maintenance and calibration.

This report documents the electronics redesign which was developed. Test results are provided which demonstrate that the redesign meets the accuracy specifications of the original instrument.

## SOUND VELOCIMETER OPERATION

The NUS model 1020 sound velocimeter is a hull-mounted device through which seawater is pumped at a rate of approximately three gallons per minute. The seawater sound speed is measured on a continuous basis to an accuracy of $\pm.15$ meters per second (m/s) over a range of 1400 to 1550 m/s.[1]

The velocimeter is based upon the sing-around principle developed by C.E. Tschiegg and M. Greenspan of the National Bureau of Standards. A pair of piezoelectric ceramic transducers and two reflectors are mounted to form a sound path of fixed length in the water (see appendix C, figure 1). This sound path along with the transducers and associated electronic circuitry form the essential operating components of the sing-around circuit. During operation, a pulse of acoustic energy is transmitted through the water, received, amplified and used to generate another pulse of acoustic energy. The repetition frequency of this regenerative action is proportional to the transit time of the signal pulse and is therefore a measure of the sound propagation velocity. Errors resulting from the variations of water flow along the sound path length are minimized by folding the sound path.

[1] The range specification for the original unit was 1400 to 1700 m/s. The 1550 m/s upper limit represents sound velocity in 40 ppt seawater at 30$^{\circ}$C.

## REDESIGN GOALS

In order to minimize the redesign effort and to utilize as many of the original sound velocimeter components as possible, the following goals were set:

1. Upgrade the design of the original sound velocimeter signal processing electronics such that the new design is a "black box" replacement of the existing encapsulated electronics.
2. The new design must allow for operation over a temperature range of 0°C to 35°C.
3. The accuracy and resolution must equal or exceed the original design specifications.
4. The completed design must fit into the existing electronics housing.

These goals led to the design and fabrication of a prototype sound velocimeter in September 1981. A Nusonics Model SDS-1 deep-sea sound velocimeter was retrofitted with the new electronics design.[2] (See appendix B for a detailed description of the circuit operation.) Test results demonstrate that all of the design goals have been achieved.

After tests of the prototype, additional circuit boards were built, spare parts were obtained, and the electronics documentation finalized. The first unit using model 1020 hardware was built and successfully tested in January 1982. In order to provide total support, the mechanical components were documented and fabricated. Finally, a source for spare piezoelectric transducers having the necessary characteristics was found. These characteristics are provided in appendix C, figure 3.

## CALIBRATION

The calibration of the velocimeters is performed in the NAVOCEANO Sensor Calibration Laboratory. The velocimeters are placed in a 250 gallon precision temperature controlled environmental bath at 35 ppt salinity. The sensor output frequency is adjusted to 6000 ± 1 Hz at a bath sound velocity of 1492 m/s. The bath temperature is monitored using a Leeds and Northrop Platinum Resistance Thermometer and a Guildline Model 9985 Current Comparator Bridge.[3] Bath salinity is determined by measuring a water sample using a Guildline Model 8400 Autosal.[4] Bath sound velocity is determined using the Del Grosso equation for seawater.[5]

After the adjustment at 1492 m/s, the velocimeter is tested at seven different bath temperatures beginning at 30°C and decreasing by 5°C increments to 0°C. Temperature, salinity and velocimeter frequency are recorded at each test temperature.

[2] The SDS-1 hardware was used, since at the time no model 1020 hardware was available for prototype development.

[3] The temperature uncertainty using this measurement is ± 0.003°C.

[4] The Guildline Model 8400 Autosal has a short term stability of better than ± 2 ppm equivalent salinity for 24 hours without restandardization.

[5] Del Grosso, V.A., "New Equation for the Speed of Sound in Natural Waters (with comparisons to other Equations)", Journal of the Acoustical Society of America, Vol. 56, No. 4, October 1974.

## TEST RESULTS

Velocimeter test results are listed in appendix A, tables 1 - 5. The output frequency of the velocimeter is recorded for each test point. Bath sound velocity is determined from the temperature and salinity measurements using the Del Grosso equation. The computed velocimeter sound velocity is determined from a first order linear least squares fit. The fit coefficients are listed under each table, where: $SV = C_1 + C_2(Freq)$. The residuals are determined by subtracting the computed velocimeter sound velocity from the bath sound velocity.

Table 1 lists the data obtained from the prototype unit developed using model SDS-1 sound velocimeter hardware. Table 2 presents data from the first working velocimeter fabricated using model 1020 hardware. Tables 3 and 4 list results for a second velocimeter before and after deployment aboard the USNS HESS in August 1982 during a two month field test. Table 5 shows the test results for the first velocimeter built using new electronics and newly fabricated hardware including new transducer assemblies. These data show that after adjustment and calibration, all the new velocimeters demonstrate sound velocity residuals substantially less than the required accuracy specification of $\pm$ .15 meters per second.

## CONCLUSIONS

The electronics redesign of the Nusonics Model 1020 sound velocimeter has met and exceeded all of the accuracy specifications of the original design. Sound velocimeter, S.N. 7, was deployed for two months aboard the USNS HESS without apparent measurement degradation. However, since these units are deployed for as much as a year, long term stability tests must be performed. Such tests are presently underway and should complete the evaluation of the new electronics. With the availability of new hardware and piezoelectric transducers, total depot level support for these instruments now exists in the Instrumentation and Metrology Branch of the Naval Oceanographic Office.

APPENDIX A

TABLES

TABLE 1

MODEL SDS-1 VELOCIMETER PROTOTYPE REDESIGN

| VELOCIMETER FREQUENCY (HERTZ) | BATH SOUND VELOCITY METERS/SECOND | COMPUTED VELOCIMETER S.V. METERS/SECOND | RESIDUALS METERS/SECOND |
|---|---|---|---|
| 6973.598 | 1449.111 | 1449.098 | -.013 |
| 7077.141 | 1470.716 | 1470.709 | -.008 |
| 7167.996 | 1489.675 | 1489.671 | -.004 |
| 7248.846 | 1506.536 | 1506.545 | .009 |
| 7319.894 | 1521.380 | 1521.374 | -.006 |
| 7381.327 | 1534.215 | 1534.195 | -.020 |

Fit Coefficients:

C1 = -6.36150

C2 = .208710

Standard Error of Estimate = .011 meter/second

TABLE 2

MODEL 1020 VELOCIMETER

S.N. 2350 NEW ELECTRONICS

| VELOCIMETER FREQUENCY (HERTZ) | BATH SOUND VELOCITY METERS/SECOND | COMPUTED VELOCIMETER S.V. METERS/SECOND | RESIDUALS METERS/SECOND |
|---|---|---|---|
| 5838.359 | 1449.179 | 1449.067 | -.112 |
| 5924.802 | 1470.781 | 1470.793 | .012 |
| 6000.456 | 1489.742 | 1489.808 | .066 |
| 6067.446 | 1506.593 | 1506.646 | .053 |
| 6126.025 | 1521.390 | 1521.369 | -.021 |
| 6177.339 | 1534.271 | 1534.266 | -.005 |
| 6220.917 | 1545.324 | 1545.219 | -.105 |

Fit Coefficients:

C1 = -18.3461

C2 = .251340

Standard Error of Estimate = .067 meter/second

TABLE 3

MODEL 1020 VELOCIMETER

S.N. 7 PRECRUISE

| VELOCIMETER FREQUENCY (HERTZ) | BATH SOUND VELOCITY METERS/SECOND | COMPUTED VELOCIMETER S.V. METERS/SECOND | RESIDUALS METERS/SECOND |
|---|---|---|---|
| 5826.250 | 1448.775 | 1448.707 | -.067 |
| 5912.052 | 1470.301 | 1470.302 | .001 |
| 5987.630 | 1489.292 | 1489.324 | .032 |
| 6054.405 | 1506.116 | 1506.130 | .014 |
| 6112.955 | 1520.848 | 1520.866 | .018 |
| 6163.974 | 1533.730 | 1533.706 | -.024 |
| 6208.057 | 1544.867 | 1544.801 | -.066 |

Fit Coefficients: Standard Error of Estimate = .040 meter/second

C1 = -17.6430

C2 = .251680

TABLE 4

MODEL 1020 VELOCIMETER

S.N. 7 POSTCRUISE

| VELOCIMETER FREQUENCY (HERTZ) | BATH SOUND VELOCITY METERS/SECOND | COMPUTED VELOCIMETER S.V. METERS/SECOND | RESIDUALS METERS/SECOND |
|---|---|---|---|
| 5825.469 | 1448.643 | 1448.574 | -.069 |
| 5911.598 | 1470.281 | 1470.244 | -.037 |
| 5987.378 | 1489.286 | 1489.310 | .024 |
| 6054.441 | 1506.150 | 1506.183 | .033 |
| 6113.067 | 1520.951 | 1520.934 | -.017 |
| 6164.354 | 1533.862 | 1533.837 | -.025 |
| 6208.134 | 1544.939 | 1544.852 | -.087 |

Fit Coefficients: Standard Error of Estimate = .048 meter/second

C1 = -17.1142

C2 = .251600

TABLE 5

MODEL 1020 VELOCIMETER

NEW TRANSDUCERS & ELECTRONICS

S.N. 2351

| VELOCIMETER FREQUENCY (HERTZ) | BATH SOUND VELOCITY METERS/SECOND | COMPUTED VELOCIMETER S.V. METERS/SECOND | RESIDUALS METERS/SECOND |
|---|---|---|---|
| 5826.792 | 1449.143 | 1449.109 | -.034 |
| 5911.668 | 1470.464 | 1470.438 | -.027 |
| 5986.841 | 1489.336 | 1489.328 | -.008 |
| 6053.488 | 1506.103 | 1506.075 | -.028 |
| 6112.059 | 1520.787 | 1520.994 | .007 |
| 6162.948 | 1533.600 | 1533.582 | -.018 |
| 6207.016 | 1544.709 | 1544.655 | -.054 |

Fit Coefficients:

C1 = -15.1057

C2 = .251290

Standard Error of Estimate = .029 meters/second

APPENDIX B

DETAILED DESCRIPTION OF REDESIGNED SOUND VELOCIMETER ELECTRONICS

## DETAILED DESCRIPTION OF REDESIGNED SOUND VELOCIMETER ELECTRONICS

### Background

The electronics circuit design has been developed to upgrade the electronics in the Nusonics Model 1020 sound velocimeter (SV) utilizing readily available components. The small printed circuit board developed replaces many discrete components utilized in the original design. The new circuit design uses low-power "B" series complementary metal oxide semiconductor (CMOS) electronics.

### Circuit Operation

There are six major elements in the design (see figure 2). They are: (1) input power regulator; (2) sing-around oscillator; (3) receiver lock-out one-shot (1/S); (4) transmit pulse driver; (5) received pulse amplifier and level shifter; and (6) negative voltage converter.

The operation of the input power regulator is straight-forward. Provisions have been made for input power, either from the built-in transformer/rectifier or from an external DC source of 15 to 35 volts. The regulator, an LM340T-12, is arranged so that the heat sink tab can be mounted to an aluminum mounting plate which is part of the mechanical package. This heat sink arrangement reduces junction temperatures within the regulator. The regulator output of 12 VDC supplies power to the rest of the circuit.

The sing-around oscillator consists of the dual 1/S, U1. The initial edge which starts the oscillation is derived from the R/C network on the B input to U1A (Pin 2). The time constant of this network (R1, C1) is approximately 2 ms. When power is first applied, the 12 V VCC to the logic is applied well before pin 2 reaches the trigger threshold. The positive going transition on pin 2 starts the oscillation by triggering the 1/S, U1A. U1A fires and the Q-complement output, 75μs wide, is applied to the B input of the U1B (Pin 10). At the end of the pulse, the low-to-high transition triggers U1B whose period is 180μs. The Q output of U1B (Pin 5) is connected to the A input of U1A (Pin 1). This initiates another cycle. The combined response period for both U1A and U1B is approximately 250μs, which results in a 4 KHz square wave. This is the output frequency for free-run conditions when the SV is not immersed in water.

If for any reason the oscillator stops running, the NAND gate, U3B, is connected to both of the 1/S's Q-complement outputs. Both of these levels will be high when the oscillator stops, setting pin 6 of U3B low. This high-to-low transition, through C1, will result in another restart low-to-high edge at pin 2 of U1A.

The receiver lock-out 1/S, U2A, is triggered by the low-to-high transition of the Q-complement output from U1B (Pin 12). The Q-complement output from U2A (Pin 4) closes the NAND gate, U3A (Pin 2), which prevents the transmit pulse from prematurely terminating a cycle. This is necessary since the acoustic pulse takes a direct path from transducer to transducer as well as the desired path via the reflectors. On the leading edge of the U2A Q output, the 1/S U2B is triggered. U2B is connected for minimum pulse width output by excluding external capacitance and reducing the external resistance to a minimum. The output pulse width from U2B is approximately 200 ns. The transducer is driven by the fast buffer amplifier, consisting of Q2 and Q5. This push-pull structure was chosen to ensure sharp edges on both sides of the transmit pulse.

When the unit is placed in water, the transmitted acoustic pulse is detected by the receive transducer. When an oscilloscope is placed on the output of U5, pin 6, two pulses are evident. The first is the transmit pulse which propagates directly from the transmit transducer to the receive transducer bypassing the acoustic reflectors. As previously described, this pulse is locked out by the NAND gate U3A. The pulse of interest which has traversed the desired path length of the SV is detected afterwards. By the time of its arrival, the 1/S U2A has timed out and the received pulse, level shifted for the logic by transistors Q3 and Q4, is passed by NAND gate U3A. The output from U3A, pin 3, shortens the period of 1/S U1B by resetting it prior to its normal time-out. This immediately initiates another cycle in the oscillator. Thus, when in water, the frequency seen at the output is approximately 7 KHz for the over-the-side unit (SDS-1). Since the path length of the hull-mounted version is longer (25 cm versus 20 cm), the frequency seen in the hull-mounted version is approximately 5.6 KHz in water.

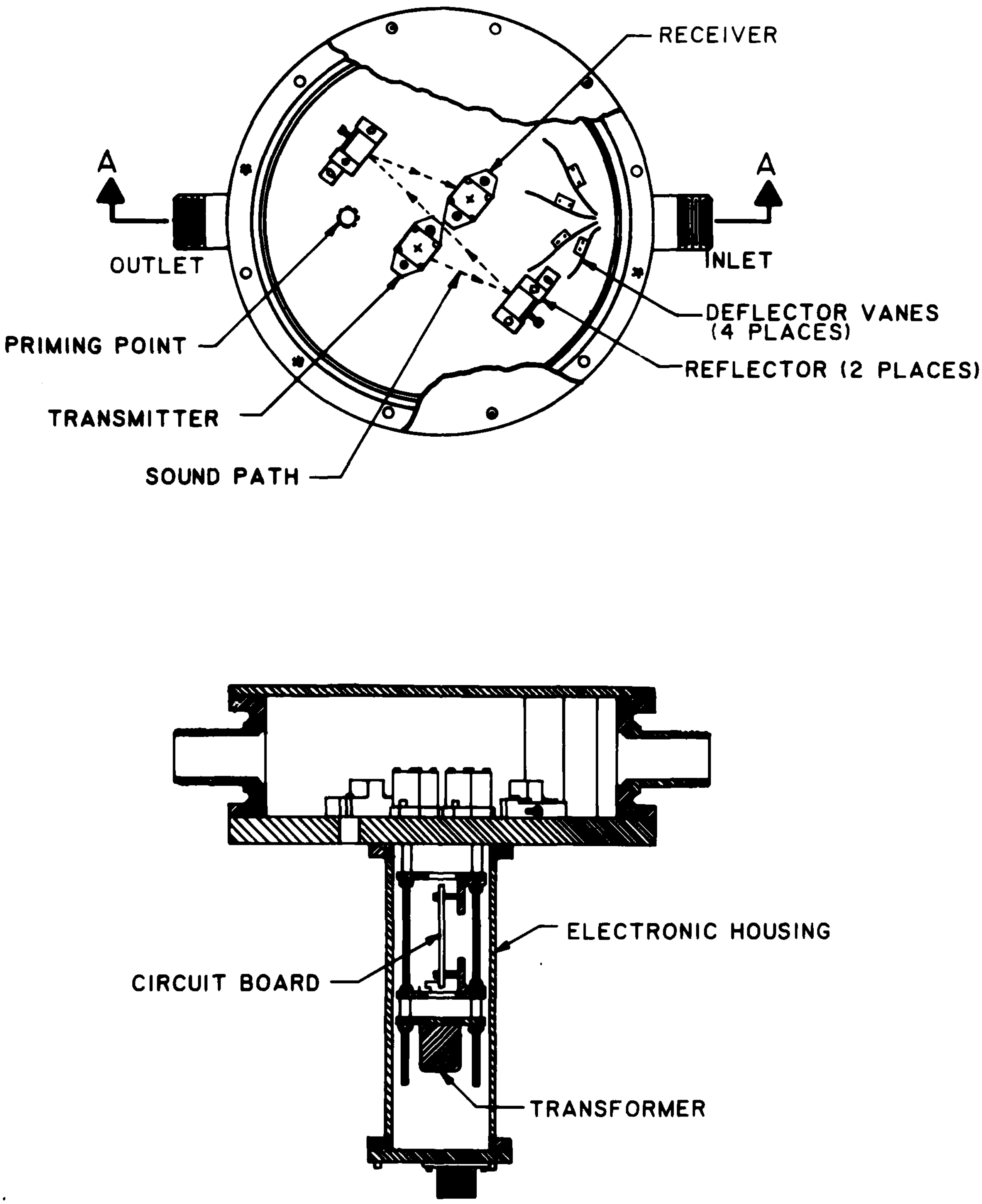
The negative voltage converter, U6, serves to provide negative voltage for the proper operation of the op-amp U5. U6 is driven by gate U3C which buffers the signal from U1B. U6 works best when driven by roughly symmetric square waves. The U1B signal is used because it is roughly symmetric when the unit is operated under water. The Zener diode, CR3, reduces the 12 V to approximately 5 V. The input to U6 (Pin 7) cannot exceed the voltage on pin 8. The voltage divider, consisting of R9 and R10, reduces the amplitude of the 12 V signal output at pin 8 of U3C to approximately 5 V. The output of U6 on pin 5 is filtered by capacitor C11. Additional filtering is provided by capacitors C14 and C15. The output of the unit is buffered by the driver Q1 and is provided to Terminal 5 of the printed circuit board.

The measured time delay from the first received signal to the leading edge of the transmit pulse is less than 200 ns. Care was taken to ensure that the variability in this fixed time delay did not result in excessive jitter for the unit. The remainder of the pulse period is represented by the round-trip time of the sonic pulse through the prescribed path. Thus, the 200 ns internal logic delay represents only 0.10 of one percent of the total period. The variability of this 200 ns time period, an absolute maximum of 20 percent over the design temperature range, represents only 0.03 percent of the period, which is well within the specified 0.05 percent designed accuracy for the original velocimeter electronics.

APPENDIX C

FIGURES

# SOUND VELOCIMETER



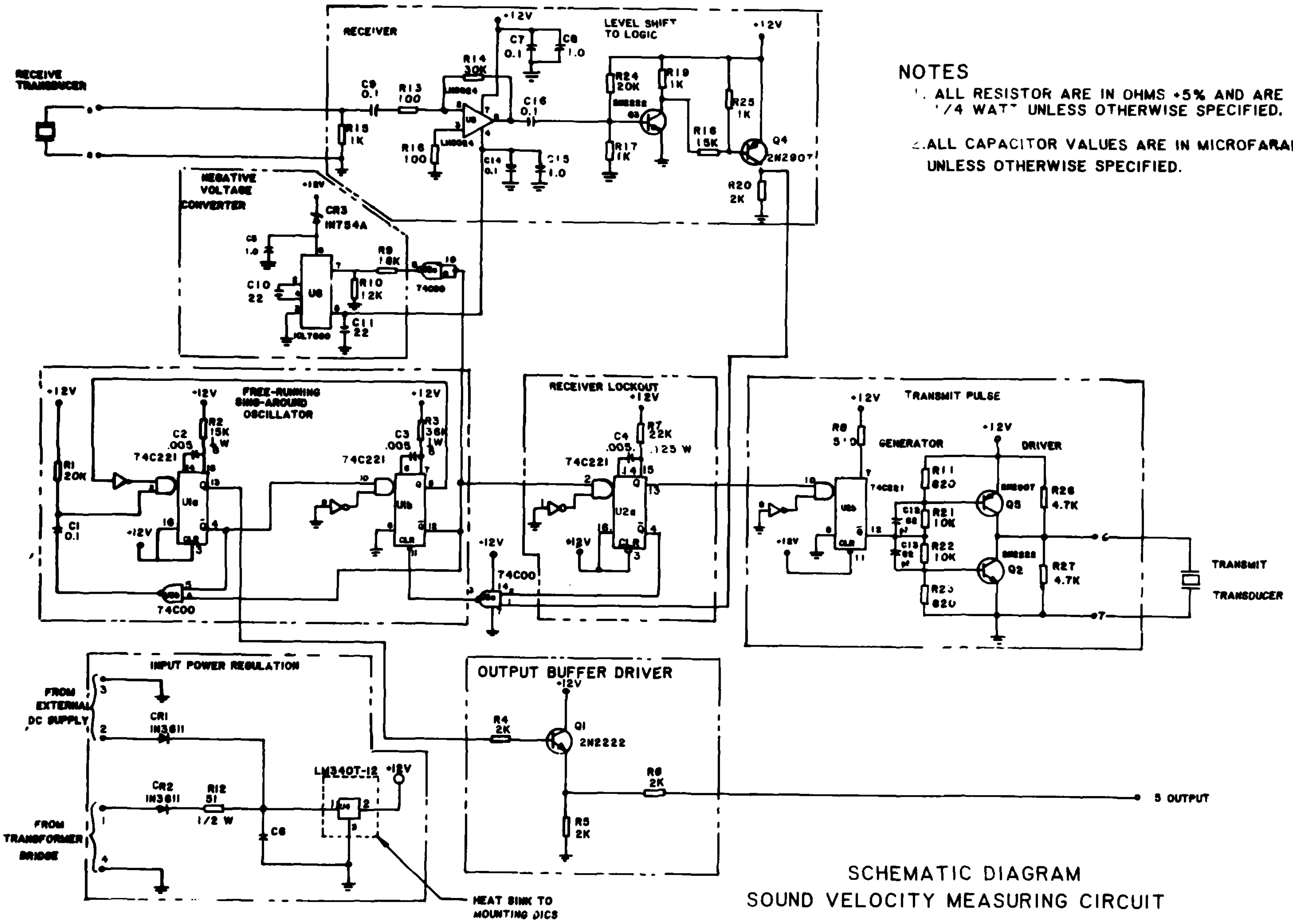

SECTION A-A

**FIGURE 1.**

NOTES

1. ALL RESISTOR ARE IN OHMS ±5% AND ARE 1/4 WATT UNLESS OTHERWISE SPECIFIED.

2. ALL CAPACITOR VALUES ARE IN MICROFARADS UNLESS OTHERWISE SPECIFIED.




SCHEMATIC DIAGRAM
SOUND VELOCITY MEASURING CIRCUIT

**FIGURE 2.**

# CERAMIC TRANSDUCER

SPECIFICATION:

.500 $^{+.000}_{-.005}$ O.D.

.021 ± .001 THICK

GOLD ELECTRODES - SOLID ONE SIDE

.250 O.D. - OPPOSITE SIDE

1 - No. 26 AWG SOLID TINNED COPPER WIRE, ONE INCH LONG SOLDERED ON .250 O.D. ELECTRODE SIDE.

FREQUENCY 3.6 MEGAHERTZ

MATERIAL:

PZT-5

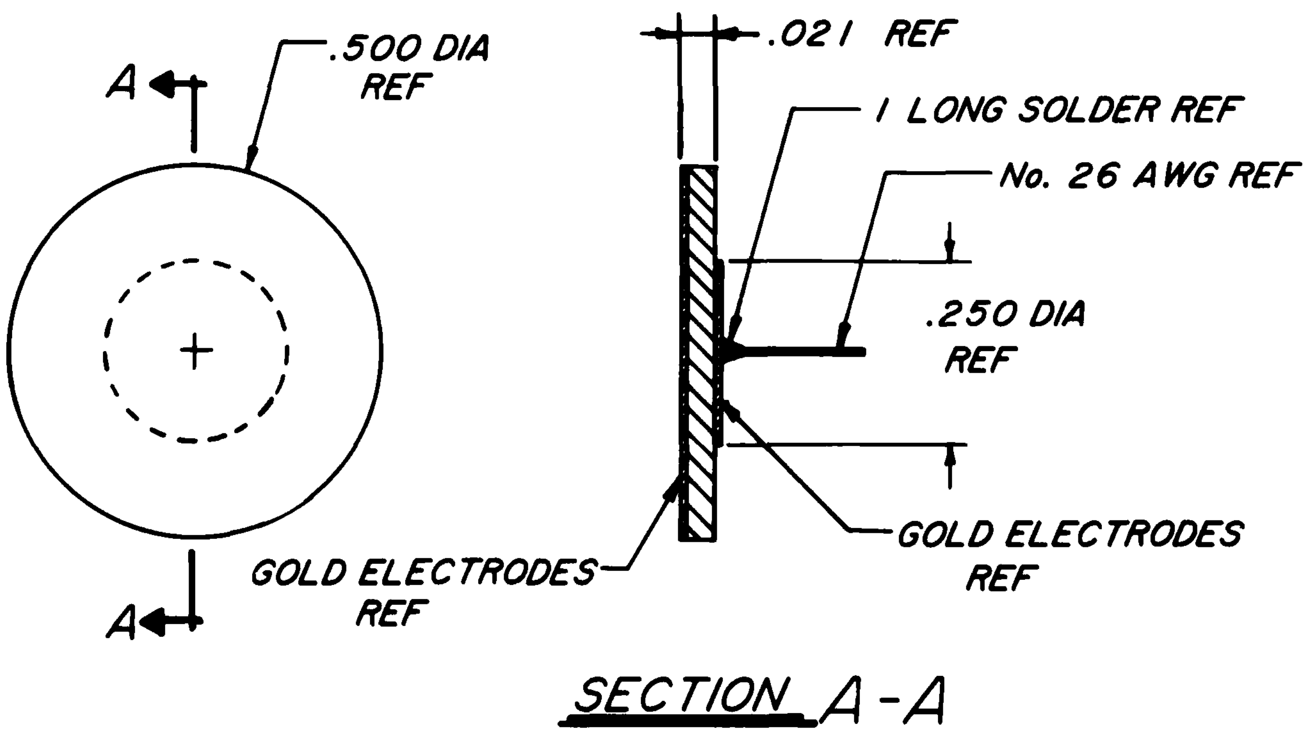



FIGURE 3

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